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2. Patent application number *(The Patent Office will fill in this part)* — 0326070.0 — 7 NOV 2003

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   Newage International Limited
   P O Box 17
   Barnack Road, Stamford
   Lincolnshire PE9 2NB
   United Kingdom

   Patents ADP number *(if you know it)* — 69669/5001

   If the applicant is a corporate body, give the country/state of its incorporation — United Kingdom

4. Title of the invention

   An AC Power Generating System

5. Name of your agent *(if you have one)* — fJ Cleveland

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

   40-43 Chancery Lane
   London WC2A 1JQ

   Patents ADP number *(if you know it)* — 07368855001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Claim *(s)*	8
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11. I/We request the grant of a patent on the basis of this application.

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Mr C J W Everitt 020 7405 5875

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An AC Power Generating System

This invention relates to an AC power generating system.

WO01/56133 discloses an AC power generating system of the kind that comprises a controllable source of power arranged to provide a variable voltage and/or current electrical output, convertor means for generating an AC power output to supply a load from the variable voltage and/or current electrical output such that the AC power output is substantially independent of variations in the electrical output of the controllable source, and control means which are operable to control the operation of the controllable source and the convertor means and thereby to supply the power required by the load, the control means being operable in response to signals derived from sensed current and/or voltage of an electrical output which is generated by the convertor means from the electrical output of the controllable source and which is substantially independent of variations in the electrical output of the controllable source. Such an AC power generating system will be referred to in this description an AC power generating system of the kind referred to hereinbefore.

During normal independent operation of the generating set described and illustrated in WO01/56133, the output AC voltage is controlled in accordance

with one or more references which are generated by or within the generating set or as it is being set up for operation. Active and reactive power consumption is dependent on loads to which the AC power output of the generating set is connected.

An object of this invention is to provide for connection and disconnection of the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid.

Connection and/or disconnection of the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid needs to take account of the fact that the grid voltage may be out of phase and at a different frequency to the AC power output of the AC power generating system of the kind referred to hereinbefore when the latter is being operated independently.

Broadly in accordance with this invention the control of the AC power output of an AC power generating system of the kind referred to hereinbefore is disabled and the AC power output of the AC power generating system of the

generated by or within the generating set or that were established as the generating set was being set up for operation and which determined the AC output voltage, are replaced by references derived from the grid data. Whereas only the AC output voltage of an AC power generating system of the kind referred to hereinbefore is controlled during independent operation of that system, active and reactive power transmitted to the grid are adjusted and controlled when the AC power output of the AC power generating system of the kind referred to hereinbefore is connected to the power supply grid.

According to one aspect of this invention there is provided a method of operating an AC power generating system of the kind referred to hereinbefore in order to connect its AC power output to a power supply grid, wherein the current and voltage of the AC power output and the voltage of the power supply grid are monitored and one reference which is derived from the monitored AC power output current and voltage and which is used as a reference in the operation of the convertor means to control the generation of that AC power output during independent operation of the AC power generating system of the kind referred to hereinbefore is replaced by another reference which is derived from the monitored grid voltage when the AC power output is connected to the power supply grid, the arrangement being such that generation of the AC power output by the convertor means of the AC

power generating system of the kind referred to hereinbefore is controlled in accordance with the other reference that is derived from the monitored grid voltage when the AC power output of the AC power generating system of the kind referred to hereinbefore is connected to the power supply grid.

Preferably operation of said controllable source by said control means when the AC power output is connected to the power supply grid, is in response to the monitored current and voltage of the AC power output so that active and reactive power that are transmitted to the power supply grid are adjusted and controlled in accordance with the voltage of the grid. The AC power output current for the or each phase may be monitored between the inductor and the capacitor of an LC filter for that phase.

Conveniently, the method includes feeding the monitored AC power output current and voltage to voltage reference generator means which produce one output signal and comparing said one output signal with the monitored AC power output voltage in a voltage controller which responds by producing said one reference. The method may also include the step of deriving a voltage reference signal from the monitored grid voltage, feeding that voltage reference [illegible]

phase and amplitude progressively towards those of said voltage reference signal, and delaying connection of said AC power output to the grid until after said one reference and said voltage reference signal are substantially overlapping in phase and amplitude. The voltage reference signal may be fed to said voltage controller instead of said one output signal, said voltage controller being operated to compare said voltage reference signal with said monitored AC output voltage to produce said one reference once said one reference signal and said voltage reference signal are substantially overlapping in phase and amplitude. The said one reference may be replaced by said other reference once said output signal has been replaced by said voltage reference signal.

Conveniently said other reference is derived from said voltage reference signal It may also be derived from an active power reference and a reactive power reference.

The method may also include the step of reconnecting said one output signal to said voltage controller and replacing said other reference by said one reference in the event of disconnection of the AC power output of the AC power generating system of the kind referred to hereinbefore from the power supply grid or loss of the grid voltage, so that said AC power generating system of the kind referred to hereinbefore operates independently.

According to another aspect of this invention there is provided a system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid, comprising means operable to monitor the current and voltage of the AC power output and the voltage of the power supply grid, means for deriving one reference from the monitored AC power output current and voltage, said one reference being for use as a reference in the operation of the convertor means of the AC power generating system of the kind referred to hereinbefore to control the generation of that AC power output during independent operation of the AC power generating system of the kind referred to hereinbefore, means for deriving another reference from the monitored grid voltage and control means operable to replace said one reference by the other reference which is derived from the monitored grid voltage when the AC power output of the AC power generating system of the kind referred to hereinbefore is connected to the power supply grid, the arrangement being such that generation of the AC power output by the convertor means of the AC power generating system of the kind referred to hereinbefore is controlled in accordance with the other reference that is derived from the monitored grid voltage when the AC power output of the AC power

Preferably the control means that are operable to control the operation of the controllable source are responsive to the monitored current and voltage of the AC power output when the AC power output is connected to the power supply grid so that active and reactive power that are transmitted to the power supply grid are adjusted and controlled in accordance with the voltage of the grid.

The AC power output current for the or each phase of the AC power output may be monitored between the inductor and the capacitor of an LC filter for that phase.

In a preferred embodiment, said one reference is derived from the monitored AC power output current and voltage by feeding the monitored AC power output current to voltage reference generator means which produce one output signal which is then compared with the monitored AC power output voltage in a voltage controller which responds by producing said one reference.

Conveniently a voltage reference signal which is derived from the monitored grid voltage is fed to the voltage reference generator means which are operable to modify said one output signal so as to change its phase and amplitude progressively towards those of the voltage reference signal, connection of the

AC power output to the power supply grid being delayed until after said one reference and the voltage reference signal are substantially overlapping in phase and amplitude. First transfer switch means may be provided which are operable once said one reference signal and said voltage reference signal are substantially overlapping in phase and amplitude, so that the voltage reference signal is fed to the voltage controller, instead of said one output signal, for comparison with the monitored AC output voltage to produce said one reference. Second transfer switch means may be provided which are operable once said one output signal has been replaced by said voltage reference signal, so that said one reference is replaced by said other reference.

The said other reference may be derived from the voltage reference signal. It may also be derived from an active power reference and a reactive power reference. The active and reactive power references may be generated arbitrarily or by feed back from the AC power generating system of the kind referred to hereinbefore.

In the event of disconnection of the AC power output of the AC power generating system of the kind referred to hereinbefore from the power supply

controller and to replace said other reference by said one reference so that said AC power generating system of the kind referred to hereinbefore operates independently.

One embodiment of this invention is described now by way of example only with reference to the accompanying drawing which is a circuit diagram of an electric power generating set which automatically varies its speed to match load variation at any time when it is operated independently and control means for that generating set to control its connection to a power supply grid. The hardware components of the generating set and the grid are shown in heavy black lines and the other elements which are shown in lighter lines are software components with which a controlling microprocessor is programmed.

The drawing shows components of an electrical power generating set in diagrammatic form. The generating set includes an engine (1) which is mechanically coupled with a rotor of a generator (2) whereby to rotate the rotor relative to a stator of the generator (2) and thereby to generate a three phase variable frequency and voltage AC output (Vg) from the generator (2).

The three phase variable frequency and voltage output (Vg) of the generator (2) is fed to an AC-AC convertor (3). The AC-AC convertor (3) is operable to

generate an AC power output for supply to a load from the three phase variable frequency and voltage output (Vg) of the generator (2) such that the AC power output is substantially independent of variations in the output (Vg) of the generator (2). The AC-AC convertor (3) may comprise the full-wave bridge rectifier (Re), the booster (BO) which establishes an intermediate DC voltage and the invertor (INV) which converts that intermediate DC voltage into a three phase AC power output which is substantially independent of variations in the output (Vg) of the generator (2), such as is described with reference to and illustrated in either Figures 1A and 1B or Figures 7A and 7B or Figures 9A and 9B of the International publication WO01/56133.

WO01/56133 explains that the reference levels for the required value of output frequency and voltage of the generating set described with reference to and illustrated in either Figures 1A and 1B, Figures 7A and 7B or Figures 9A and 9B of that document are provided by an amplitude and frequency correction circuit (AFC) which responds to signals indicative of the sensed intermediate DC voltage and current and to engine speed as well as to one or more preselected reference signals. The reference level signal for each phase is fed to an invertor controller (IC) which provides pulse width modulated signals which

set illustrated in the accompanying drawing are provided by a current controller (9). Provision of the necessary reference levels to the current controller (9) is described in detail below.

As is the case with each of the generating sets described with reference to and as illustrated in Figures 1A and 1B, Figures 7A and 7B and Figures 9A and 9B of WO01/56133, each phase of the three phase AC power output of the AC-AC convertor (3) is fed to a load (11) through a respective LC filter which comprises an inductor (4) and a capacitor (6). The current sensor (5), which is connected between each inductor (4) and the respective capacitor (6), senses the current (Iina) drawn by the load (11) from each inductor (4). A voltage sensor (10) senses the voltage of each phase of the filtered three phase AC power output from the AC-AC convertor (3) that is fed to the load (11). Output signals, (Iina and Vaca) emitted respectively by the current sensor (5) and the voltage sensor (10) and indicative of the respective sensed current or voltage, are fed to an engine controller (23) which is operable to control the speed of the engine (1). Hence the engine controller (23) is operable to adjust the speed of the engine (1) proportionally to the active power supplied to the load (11) calculated from the inductor current signal (Iina) and the output voltage signal (Vaca). The inductor current signal (Iina) emitted from the current sensor (5) is also fed to the current controller (9) and to a voltage reference generator (17)

which generates a reference voltage (Vinr) that it derives from the inductor current signal (Iina). A normally closed transfer switch (14) transmits the output signal (Vinr) from the voltage reference generator (17) to one input of a voltage controller (15) when that transfer switch (14) is in its normally closed state. The voltage controller (15) receives the voltage signal (Vaca) from the voltage sensor (10) at another input and emits a reference (Iinr) which it generates from a comparison of the output signal (Vinr) received from the voltage reference generator (17) via the transfer switch (14) and the sensed filtered AC output power voltage (Vaca) sensed by the voltage sensor (10). A second normally closed transfer switch (16) transmits the reference signal (Iinr) to the current controller (9) when in its normally closed state.

The reference (Iinr) generated by the voltage controller (15) is used as the reference level for the required value of output frequency and voltage emitted by the AC-AC convertor (3) as described above, since the current controller (9) compares the inductor current signal (Iina) with the reference (Iinr) to produce the pulse width modulated signals for controlling switching of transistors of the AC-AC convertor (3) during normal independent operation of the generating set.

voltage sensor (10), the engine controller (23), the transfer switches (14 and 16), the voltage controller (15) and the voltage reference generator (17) are provided by a suitably programmed microprocessor.

In order to connect the AC power output of the generating set to a power supply grid (8), the voltage control arrangement of the generating set which is based on the reference signal (Iinr) emitted by the voltage controller (15) needs to be disabled and the AC output voltage of the generating set needs to be brought into equality and synchronism with the voltage of the power supply grid (8) since the latter is liable to be out of phase and at a different frequency from the AC power output of the generating set.

A switch (7) is provided for connecting the AC power output of the generating set that is connected to the load (11) to the power supply grid (8). However before the switch is activated by a grid connection system controller (18) to connect the AC power output of the generating set to the grid (8), the grid voltage (Vacg) is monitored by a voltage sensor (12) which emits a voltage reference signal (Vga) which is indicative of the voltage of the grid (8) and which is connected to an input of a phase lock loop system (13). The phase lock loop system (13) produces a sinusoidal signal (Vgrr) which follows the grid voltage (Vacg) very precisely and which is fed to both another controllable

switch (22) and to the normally open terminal of the transfer switch (14). The controllable switch (22) is normally open but is closed by an actuating signal (SSyn) fed to it by the grid connection system controller (18) when the latter receives a signal Mo which is for initiating connection of the generating set to the power supply grid (8). The output (Vga) of the voltage sensor (12) which is indicative of the voltage of the grid (8), the output signal (Vinr) from the voltage reference generator (17) and the output (Vgrr) of the phase lock loop system (13) are fed to the grid connection system controller (18). The normally open switch (22) is closed by the signal (Ssyn) fed to it by the grid connection system controller (18) so that the output (Vgrr) of the phase lock loop system (13) is fed to the voltage reference generator (17). The voltage reference generator (17) reacts to receipt of the signal (Vgrr) by slowly and smoothly changing its output signal (Vinr) towards the output (Vgrr) of the phase lock loop system (13). This continues until the two signals (Vinr) and (Vgrr) are overlapping in both amplitude and frequency. When the grid connection system controller (18) senses that that overlapping condition has been achieved, the grid connection system controller (18) produces a signal (S2) which actuates a change of state of the transfer switch (14) from its normally closed state to the open state in which the output (Vgrr) of the phase lock loop system (13) is fed

controller (15) is derived from a comparison of the output (Vgrr) of the phase lock loop system (13) which is derived from the voltage of the grid (8), with the voltage of the filtered AC power output of the AC-AC convertor (3). The grid connection system controller (18) then produces a signal (S1) which actuates a change of state of the second transfer switch (16) from its normally closed state to its open state which results in disconnection of the reference (Iinr) from the current controller (9) and its replacement by another reference (Irp) which is emitted by a reference current generator (19) which receives the output (Vgrr) from the phase lock loop system (13) as well as two reference signals (Pref) and (Qref) from an active power reference generator (20) and a reactive power reference generator (21), the other reference (Irp) being generated by the reference current generator (19) from the three inputs it receives, namely (Vgrr), (Pref) and (Qref). The active power reference (Pref) and the reactive power reference (Qref) may be determined arbitrarily or may be derived by feedback from the generating set.

Once the second transfer switch (16) has been actuated to change from its normally closed state to its open state, the grid connection controller (18) emits an actuating signal (SS) to change the state of the controllable switch (7) to connect the filtered AC power output of the AC-AC convertor (3) to the grid (8).

Whereas only the AC power output voltage of the generating set is controlled during independent operation of that generating set, active and reactive power transmitted to the grid (8) from the generating set are adjusted and controlled when the generating set is controlled by a reference derived from voltage of the grid (8). The AC power output voltage of the generating set is reoriented into synchronism with the voltage of the grid (8) quickly since the generating set is controlled by high frequency switching power transistors or other fully controllable power electronic devices and because the energy stored in the LC filter that filters the AC power output of the AC-AC convertor (3) is low. Further, since the connection of the AC power output of the generating set to the grid (8) is delayed until the reference fed to the current controller (9) is brought into a overlapping relationship with the grid voltage in both amplitude and frequency, the risk of disturbance of the operation of the load (11) is avoided.

When the controllable switch (7) is disconnected or in the event that the voltage of the power supply grid (8) fails, the grid connection system controller (18) would respond by actuating instantaneous change of state of the transfer switches (14 and 15) from their opened states to their normally closed states so

with the voltage of the filtered AC power output of the generator set in the voltage controller (15) to produce the reference that is fed to the current controller (9) for independent operation of the generating set. Since the reference signal (Vinr) was almost overlapping with the output (Vgrr) of the phase lock loop system (13) when the switch (7) was disconnected or the grid voltage failed, there is no significant disturbance in the output voltage generation by the independent operation of the generator set.

The functions of the phase lock loop system (13), the grid connection system controller (18), the current reference generator (19), the active power reference generator (20), the reactive power reference generator (21) and the switch (22) are provided by a suitably programmed microprocessor which may be the same microprocessor as provided the functions of the current controller (9), the voltage sensor (10), the engine controller (12), the transfer switches (14 and 16), the voltage controller (15) and the voltage reference generator (17).

CLAIMS

1. A method of operating an AC power generating system of the kind referred to hereinbefore in order to connect its AC power output to a power supply grid, wherein the current and voltage of the AC power output and the voltage of the power supply grid are monitored and one reference which is derived from the monitored AC power output current and voltage and which is used as a reference in the operation of the convertor means to control the generation of that AC power output during independent operation of an AC power generating system of the kind referred to hereinbefore is replaced by another reference which is derived from the monitored grid voltage when the AC power output is connected to the power supply grid, the arrangement being such that generation of the AC power output by the convertor means of the AC power generating system of the kind referred to hereinbefore is controlled in accordance with the other reference that is derived from the monitored grid voltage when the AC power output of the AC power generating system of the kind referred to hereinbefore is connected to the power supply grid.

2. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 1, including controlling the operation of said controllable source by said control means in response to the monitored current and

grid are adjusted and controlled in accordance with the voltage of the grid.

3. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 1 or claim 2, wherein the AC power output current for the or each phase is monitored between the inductor and the capacitor of an LC filter for that phase.

4. A method of operating an AC power generating system of the kind referred to hereinbefore according to any one of the claims 1 to 3, including feeding the monitored AC power output current and voltage to voltage reference generator means which produce one output signal and comparing said one output signal with the monitored AC power output voltage in a voltage controller which responds by producing said one reference.

5. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 4 when appended to claim 2, including the step of deriving a voltage reference signal from the monitored grid voltage, feeding that voltage reference signal to said voltage reference generator means, operating said voltage reference generator means to modify said one output signal so as to change its phase and amplitude progressively towards those of said voltage reference signal, and delaying connection of said AC power output to the grid until after said one reference and said voltage reference signal are substantially overlapping in phase and amplitude.

6. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 5, including feeding said voltage reference signal to said voltage controller instead of said one output signal, operating said voltage controller to compare said voltage reference signal with said monitored AC output voltage to produce said one reference once said one reference signal and said voltage reference signal are substantially overlapping in phase and amplitude.

7. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 6, wherein said one reference is replaced by said other reference after said output signal has been replaced by said voltage reference signal.

8. A method of operating an AC power generating system of the kind referred to hereinbefore according to any one of claims 1 to 7, including deriving said other reference from said voltage reference signal.

9. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 8 wherein said other reference is also derived from an active power reference and a reactive power reference.

10. A method of operating an AC power generating system of the kind referred to hereinbefore according to claim 7 or either of claims 8 and 9 when appended to claim [illegible]

the AC power output of the AC power generating system of the kind referred to hereinbefore from the power supply grid or loss of the grid voltage, so that said AC power generating system of the kind referred to hereinbefore operates independently.

11. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid, comprising means operable to monitor the current and voltage of the AC power output and the voltage of the power supply grid, means for deriving one reference from the monitored AC power output current and voltage, said one reference being for use as a reference in the operation of the convertor means of the AC power generating system of the kind referred to hereinbefore to control the generation of that AC power output during independent operation of the AC power generating system of the kind referred to hereinbefore, means for deriving another reference from the monitored grid voltage and control means operable to replace said one reference by the other reference which is derived from the monitored grid voltage when the AC power output of the AC power generating system of the kind referred to hereinbefore is connected to the power supply grid, the arrangement being such that generation of the AC power output by the convertor means of the AC power generating system of the kind referred to hereinbefore is controlled in accordance with the other reference that is derived from the monitored grid voltage when the AC power output of the AC power generating system of the kind referred to hereinbefore is connected to the power supply grid.

12. A system for connecting the AC power output of an AC power generating

system of the kind referred to hereinbefore to a power supply grid according to claim 11, wherein said control means that are operable to control the operation of the controllable source are responsive to the monitored current and voltage of the AC power output when the AC power output is connected to the power supply grid so that active and reactive power that are transmitted to the power supply grid are adjusted and controlled in accordance with the voltage of the grid.

13. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid according to claim 11 or claim 12, wherein the AC power output current for the or each phase of the AC power output is monitored between the inductor and capacitor of an LC filter for that phase.

14. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid according to any one of claims 11 to 13, wherein said one reference is derived from the monitored AC power output current and voltage by feeding the monitored AC power output current to voltage reference generator means which produce one output signal which is then compared with the monitored AC power output voltage in a voltage controller which responds by producing said one reference.

14 when appended to claim 12, wherein a voltage reference signal which is derived from the monitored grid voltage is fed to said voltage reference generator means, said voltage reference generator means being operable to modify said one output signal so as to change its phase and amplitude progressively towards those of said voltage reference signal, connection of said AC power output to the grid being delayed until after said one reference and said voltage reference signal are substantially overlapping in phase and amplitude.

16. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid according to claim 15, including first transfer switch means which are operable once said one reference signal and said voltage reference signal are substantially overlapping in phase and amplitude, so that said voltage reference signal is fed to said voltage controller instead of said one output signal for comparison with said monitored AC output voltage to produce said one reference.

17. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid according to claim 16, including second transfer switch means which are operable once said one output signal has been replaced by said voltage reference signal, so that said one reference is replaced by said other reference.

18. A system for connecting the AC power output of an AC power generating

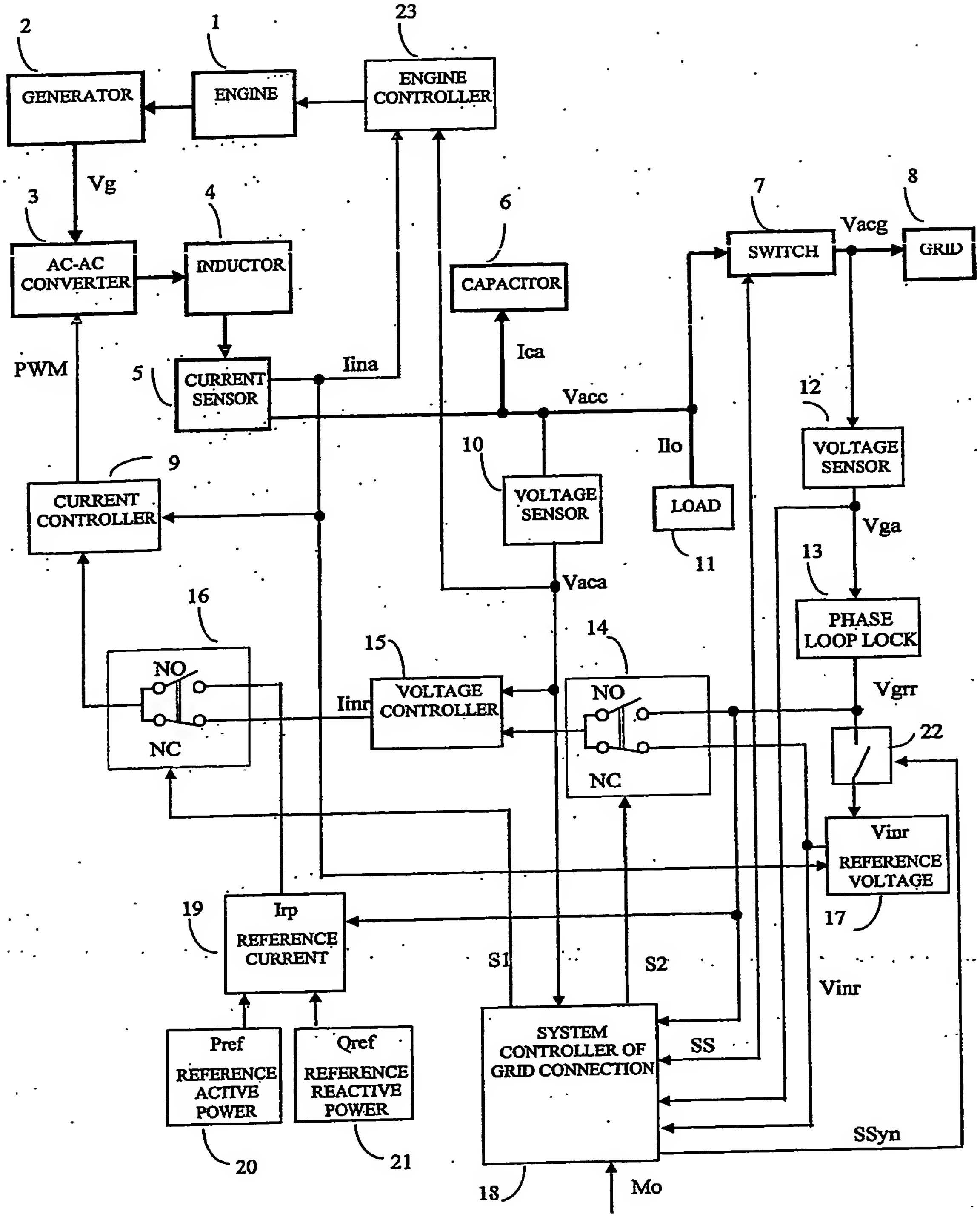
system of the kind referred to hereinbefore to a power supply grid according to any one of claims 11 to 17, wherein said other reference is derived from said voltage reference signal.

19. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid according to claim 18 wherein said other reference is also derived from an active power reference and a reactive power reference.

20. A system for connecting the AC power output of an AC power generating system of the kind referred to hereinbefore to a power supply grid according to claim 17 or either of claims 18 and 19 when appended to claim 17, wherein, in the event of disconnection of the AC power output of the AC power generating system of the kind referred to hereinbefore from the power supply grid or of loss of grid voltage, the first and second transfer means are operated to reconnect said one output signal to said voltage controller and to replace said other reference by said one reference so that said power supply apparatus operates independently.

21. A method of operating an electrical power generating set in order to connect its AC power output to a power supply grid substantially as described hereinbefore with reference to the accompanying drawing.

generating set to a power supply grid substantially as described hereinbefore with reference to and as illustrated in the accompanying drawing.


GENERATOR
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ENGINE CONTROLLER
Vg
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Fig. 1.

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